Transitions of black hole transients to the low/hard state under the microscope

E. Kalemci*, J. A. Tomsick†, R.E. Rothschild†, K. Pottschmidt**‡ and P. Kaaret§

*Space Sciences Laboratory, UC Berkeley, 7 Gauss Way, Berkeley, CA, 94720-7450
†CASS, UC San Diego, 9500 Gilman Dr., La Jolla, CA, 92093-0424
**Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstr. 1, 85748 Garching, Germany
‡INTEGRAL *Science Data Centre, Chemin d'Écogia 16, 1290 Versoix, Switzerland*
§Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA, 02138

Abstract. We characterized the evolution of spectral and temporal properties of several Galactic black hole transients observed between 1996-2001 using the data from well sampled PCA observations close to the transition to the low/hard state [1]. We showed that the changes in temporal properties are much sharper than the changes in the spectral properties, and it is much easier to identify a state transition with the temporal properties. The ratio of the power-law flux to the total flux in the 3-25 keV band increases close to the transition, and the power-law flux shows a sharp increase along with the changes in temporal properties during the transitions [2]. In this work we concentrate on the decay of two recent outbursts, from 4U 1543−47, and H1743−322 and discuss the state transitions by tracking their daily, and sometimes hourly evolution, and interpret results based on the expectations from our earlier observations.

INTRODUCTION

The evolution of spectral and temporal properties for all Galactic Black Hole (GBH) transients that have been observed with *RXTE* between 1996 and 2001 that made a state transition during outburst decay was systematically studied in the dissertation of E. Kalemci [1]. For the spectral analysis, the data were fitted with a multi-component spectral model consisting of a power-law, a multi-color disk blackbody, a broad absorption edge (*smedge* model in XSPEC)with interstellar absorption. Power spectrum from each observation in 3 - 25 keV band was also created and fitted with Lorentzians. 5 sources in 8 outbursts were covered very well with *RXTE* (close to daily monitoring), and the evolution of spectral and temporal properties from these outbursts can be summarized in Figs. 1 and 2. During outburst decays, a very sharp change is observed in rms amplitude of variability, marking state transitions (shown with dashed lines in Figs. 1 and 2). The majority of the transitions are from a thermal dominant state (TD) to the hard state (HS), however some sources go through an intermediate state (IS) before reaching the HS (see [3] for detailed definitions of these states). During the transitions, the evolutions of the spectral index, inner disk temperature and the diskbb flux are generally smooth, whereas a sharp change in power-law flux (Fig. 2.b) is usually observed along with a sharp change in temporal variability [2].

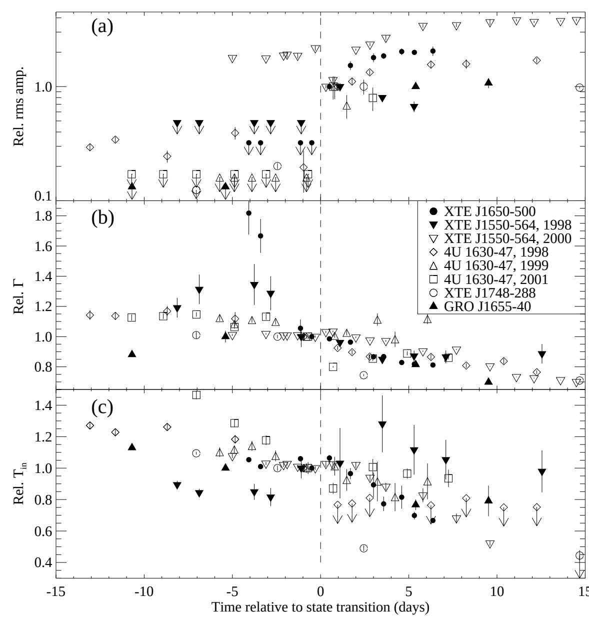

FIGURE 1. Evolution of (a) rms amplitude of variability, (b) spectral index, and (c) inner disk temperature. The state transition is assumed to have happened in between the observations closest to the sharp change observed in panel (a), and represented by a dashed line. For (a), the values for each source are normalized with respect to the value just after the state transition. For both (b) and (c), the values for each source are normalized with respect to the value just before the state transition. 1 σ errors. From [2].

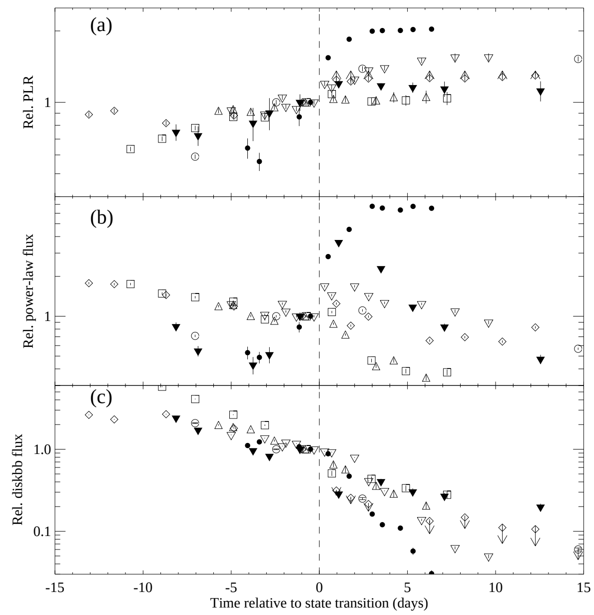

FIGURE 2. Evolution of (a) the PLR, ratio of the power-law flux to the total flux in 3-25 keV band, (b) the power-law flux, and (c) the diskbb flux. The dashed line represents the time of transition. The values for each source are normalized with respect to the value just before the state transition. 1 σ errors. From [2].

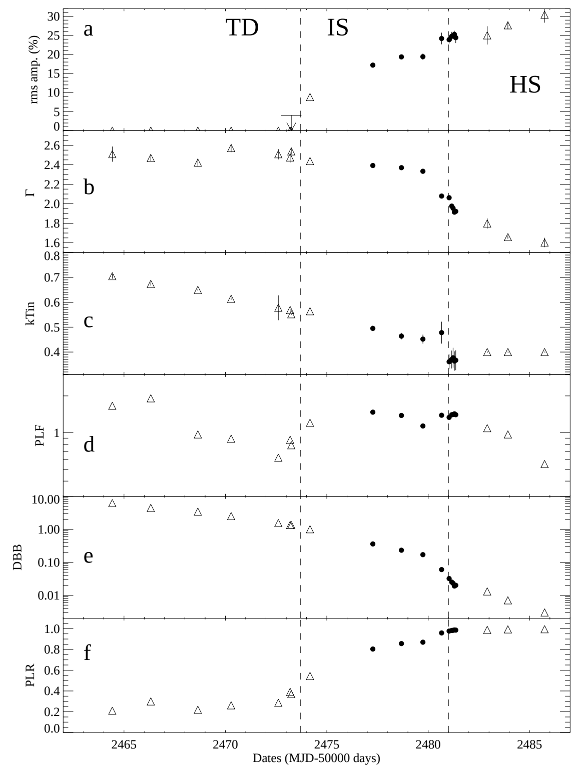

FIGURE 3. (a) Rms amplitude of variability, (b) spectral index, (c) inner disk temp., (d) power-law flux (10^{-9} ergs cm^{-2} s^{-1}), (e) diskbb flux, (f) PLR. The dashed lines represent the approximate time of state transitions. The points represented by circles also show a QPO. These observations are also used in Fig. 2.

We observed two other GBH transients during outburst decay recently, 4U 1543−47 in 2002 and H1743−322 in 2003. We applied a similar analysis technique described above to see if these sources obey the general trends. In addition to the daily 1-3 ks observations, we were also able to utilize a 20 ks observation to characterize hourly evolution of a state transition of 4U 1543−47.

4U 1543−47, DAILY AND HOURLY EVOLUTION

The spectral and temporal evolution of 4U 1543−47 right around the transition from TD to IS is shown in Fig. 3 (see also reports by M. Buxton and J. A. Tomsick on this source in this proceedings). Very weak temporal variability is observed right before the dashed line, but well defined variability appears after the dashed line. The appearance of weak variability is coincident with the increase in the power-law flux. The evolution close to the state transition is very similar to the other sources, as very smooth evolution is observed for the spectral index, disk temperature and disk flux, and a jump is observed in the power-law flux. Close to MJD 52480, another state transition is observed, this time to the HS. This transition happened right in the middle of our long 20 ks observation which enabled us to track the hourly spectral and temporal evolution of a black hole transient during a state transition.

During the second transition around MJD 52480, the inner disk temperature dropped sharply and the spectrum hardened. There was an increase in the power-law flux at the beginning which was accompanied by a jump in the rms amplitude of variability. The diskbb flux decreased an order of magnitude during this transition and finally the overall spectrum was dominated by the power-law component, hence the source was in the HS. The short term evolution of the most interesting parameters of this transition, the QPO frequency and the spectral index are shown in Fig. 4. The last 6 pointings are only 2-3 hours apart. The QPO frequency follows the spectral index very tightly. The QPO frequency - spectral index correlation has been shown before ([1, 4], see also Tomsick et al., this proceeding), but not in this kind of short time scale.

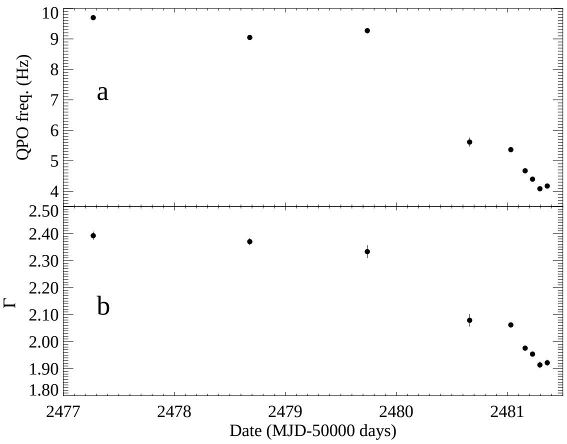

FIGURE 4. (a) the QPO frequency (for the times when the QPO is observed), (b) the spectral index of 4U 1543−47 during the state transition.

EVOLUTION OF H1743-322

The spectral and temporal evolution of H 1743−322 around the transition from TD to IS is shown in Fig. 5. Very similar to the other sources, and 4U 1543−47, the appearance of variability is coincident with a sudden increase of power-law flux. All other parameters during this transition show a smooth evolution when the variability appeared. The correlation between the power-law index and the QPO frequency is, again, apparent. The observation at ∼MJD 52933 shows an interesting behavior (shown with a different symbol in Fig. 5). The decrease in the power-law flux (and correspondingly the PLR) results in *disappearance* of variability, although the transition has happened. This indicates a tight threshold for the PLR for appearance of variability.

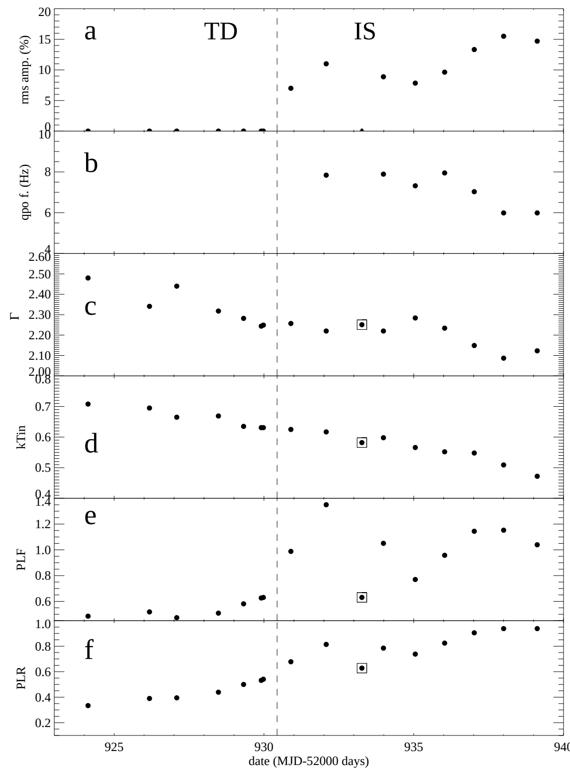

FIGURE 5. Evolution of spectral and temporal properties of H1743−322 during its decay of 2003 outburst (still in progress, Tomsick and Kalemci 5). (a) Rms amplitude of variability, (b) QPO frequency (if present) (c) spectral index, (d)inner disk temp., (e) power-law flux (10^{-9} ergs cm^{-2} s^{-1}), (f) PLR. The dashed line represent the approximate time of state transitions. A second transition to the HS may have happened around MJD 52937. The observation shown with a square symbol showed no variability.

DISCUSSION

The uniform analysis of the evolution of the spectral and temporal properties of several Galactic black hole transients during outburst decay expanded our understanding of the state transitions and creation of variability [2]. It is now clear that the appearance of variability is related to an increase in the power-law flux, and the rms amplitude of variability is related to the PLR. Both of the new outbursts that we analyzed in light of our previous results supported these arguments. A very strong correlation between the QPO frequency and the power-law index was found after our analysis of BH transients [1]. Here, we also show how tightly the QPO frequency follows the spectral index, even for a few hours timescales for 4U 1543−47. This correlation may be interpreted as both parameters being a function of the position of the inner edge of the disk. If the accretion disk is close to the BH, perhaps a larger overlap between the corona and the disk occurs, resulting stronger cooling and softer spectrum [6]. If the QPO frequency is related to a function of fundamental frequencies related to the inner edge (see for example [7]), these two parameters may be related. It is interesting that such relation (if it is the correct interpretation) holds for timescales as short as 2 hours.

The disappearance of variability in H 1743−322 with a decrease in the PLR on MJD 52933 is very interesting, but not surprising for us. The same behavior, indicating a threshold PLR for variability, was also observed during the decay of XTE J1859+226 in 2000 [2]. Fig. 6 illustrates the relation between spectral parameters and appearance of variability in XTE J1859+226. The only parameters that change considerably when the variability appeared are the power-law flux and the PLR. For this source, the variability was observed when the PLR was greater than 0.45, and it disappeared when it was below

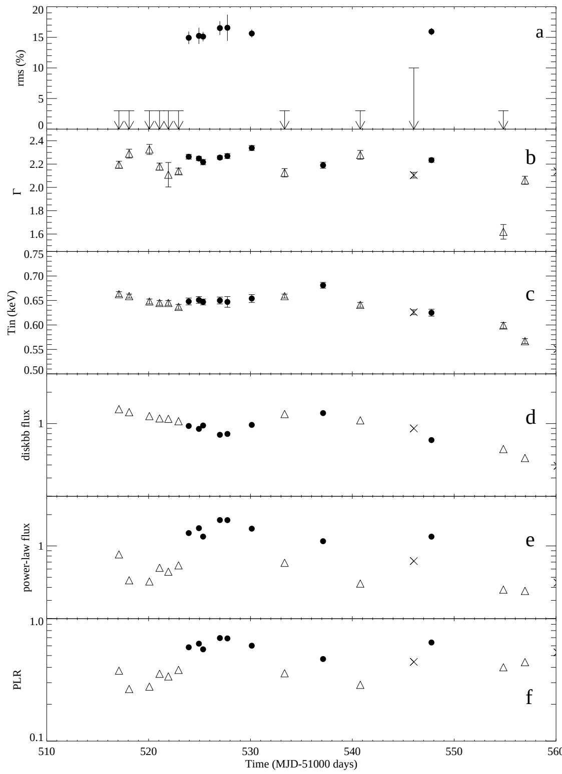

FIGURE 6. Spectral and temporal evolution of XTE J1859+226 during its outburst decay in 2000. (a) Rms amplitude of variability, (b) spectral index, (c) inner disk temp., (d) diskbb flux (10^{-9} ergs cm^{-2} s^{-1}), (e) power-law flux (same units), (f) PLR. Filled circles are used for observations with well defined variability with rms amplitude greater than 15%. The observation represented by the cross has rms amplitude less than 10%, and the remaining represented by triangles have rms amplitudes less than 3%. From [1].

this threshold value [1]. This threshold in the PLR may indicate a threshold size for the Comptonizing corona for state transitions to occur. It was argued that the mass accretion rate cannot be the "only" parameter that determines the spectral states of black hole systems, and a second independent parameter is required. Our observations support the idea that this second independent parameter is the size of the Comptonizing region as suggested earlier by Homan et al[8].

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